Proceedings of the 7th International Conference on Asian and Pacific Coasts (APAC 2013) Bali, Indonesia, September 24-26, 2013

SHORT-TERM EBB TIDAL DELTA VARIABILITY USING VIDEO IMAGERY AND MBES SURVEYS

A. Y. Ramli [1] and W. de Lange [1]

ABSTRACT: The morphology of tidal inlet deltas change in response to varying hydrodynamic conditions. Matakana Banks ebb-tidal delta is located at the Tauranga Harbour entrance. A shipping channel was dredged through the delta in 1968 and it was further enlarged in 1992. A biennial maintenance dredging programme deals with infilling of the Entrance Channel. Analysis of 13 years (1998 – 2011) bathymetric data of the swash bars on the delta indicate a very dynamic morphology. However, the main body of the ebb-tidal delta is very stable; there is no detectable response to maintenance dredging and the swash bar variability may be in response to El Niño-Southern Oscillation effects. Swash bars provide important surf breaks, and under the New Zealand Coastal Policy Statement (2010), there is a requirement to protect surfing breaks of national significance. Therefore, this study is assessing the short term response of the swash bars to dredging, and potential mitigation measure if any adverse effects are identified. This study will track swash bars response to hydrodynamic forcing using repetitive Multibeam Echosounder (MBES) surveys, continuous video monitoring of the swash bars and a major field programme. Suspended sediment data (concentration and flow field vectors) and surficial sediment distributions over the ebb tidal delta are also provided by the MBES surveys. Sediment traps are used to calibrate the MBES water column backscatter data. Three concentric transects of wave and current recorders measure the depth dependent hydrodynamic forcing across the swash platform of Matakana Banks. In order to quantify differences due to accretion or erosion, the swash bars variability is visualized from the measured cross-shore profiles and the sand volume changes determined between successive MBES surveys. The variability of the swash bars, and hence surf breaks, will be linked to suspended sediment data and waves and currents regimes.

Keywords: Morphodynamics, swash bars, surfing impact.

INTRODUCTION

An ebb-tidal delta is a complex of shoals and channels located on the seaward side of the tidal inlet (USACE, 1995). The delta consists of sand intercepted from the longshore transport system and carried seaward and deposited by ebb-tidal currents, where it is subsequently modified by waves and tidal currents (FitzGerald *et al*., 2012). The stability of an ebb tidal delta is greatly dependent on the sediment transport capacity in the tidal inlet gorge and the volume of sediment transported by longshore currents (Bruun and Gerritsen, 1960). Tidal deltas can be greatly influenced by anthropogenic activities, i.e., dredging and spoil dumping, jetties, seawall, etc (FitzGerald, 2005). In order to improve the Harbour for shipping, capital dredging began in 1968, and maintenance has occurred every 2 years since then. Expansion of the port involved further capital dredging in 1992. The Harbour is located in Bay of Plenty region, North Island of New Zealand, and now is the largest port in the country. At the seaward part of the entrance channel of the port, there is an ebb-tidal delta, with the shallow swash bars known as Matakana Banks (fig. 1).

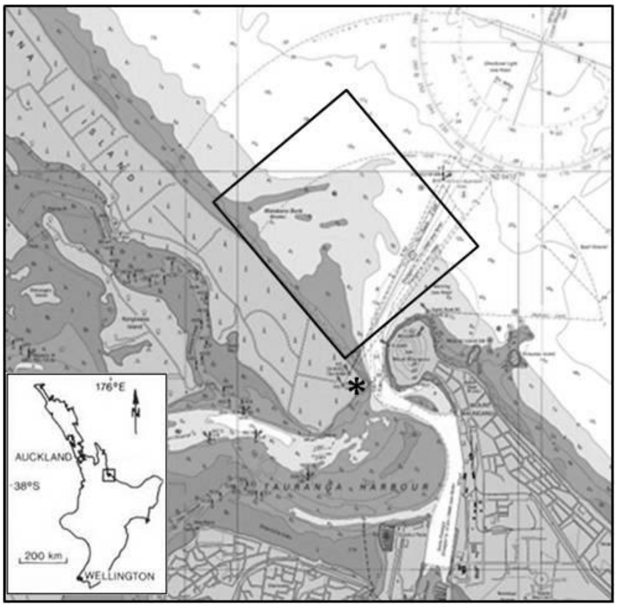

Figure 1 Study location

Matakana Banks ebb-tidal delta located at the south-eastern end of Matakana Island that extends over 3.5 km offshore of the Tauranga inlet throat. The delta type is classified as *constricted* ebb-tidal delta (Hicks and Hume, 1996) which is less elongated alongshore than the

[1] Earth and Ocean Sciences Department, University of Waikato, Private Bag 3105, Hamilton 3240, NEW ZEALAND

free-form type and occurs where the inlet occupies a broad shoreline angle and offset between a rock headland (Mt. Maunganui) and a barrier (Matakana Island) restricting the lateral spread of the delta (fig.1).

The inlet throat which acts as the harbour entrance is approximately 500 m wide with a maximum water depth of 34 m and a mean depth 15 m (Kruger and Healy, 2006). This inlet is a tide-dominated inlet, with a mean tidal range of 1.4 m and a mean annual significant wave height of 0.5 m (de Lange, 1993).

A previous study performed by Healy *et al*. (1996) indicated the delta has been largely stable in terms of its gross morphology in between 1989 and 1995 and there was no sudden or substantial change to the ebb-tidal delta which can obviously be linked to entrance channel capital dredging in 1992. However, a longer-term (1954 to 2006) bathymetric analysis that covered both capital dredging programs, performed by Brannigan (2009), indicated that the ebb-tidal delta depths vary over time by about 2 m.

The Port is planning to further enlarge the shipping channels with another phase of capital dredging. It has been suggested that this may result in significant erosion of the ebb tidal delta and nearby shorelines. This study examined the ebb tidal delta volume variability over a short time period of 13 years from 1998 to 2011 in order to assess the short-term response of the ebb-tidal delta to dredging program base on the stability of its swash bars. This work extended previous studies on the impact of dredging and spoil dumping on ebb-tidal delta i.e., by Foster *et al*. (1994), Spiers (2005), Krueger and Healy (2006), and Brannigan (2009).

DEVELOPMENT OF MATAKANA BANKS

The development of the ebb tidal is closely linked to the development of the Matakana barrier island located to the east of the present tidal inlet. The initial formation of Matakana Island is dated by the Earliest Holocene Shoreline (fig. 2) at the end of the Postglacial Marine Transgression which ended c. 7200 year BP when New Zealand approximately reached its present sea level (viz. Gibb, 1986). The island is believed to be developed by northward and southward spit extension from an intial Holocene beach formed against a remnant Pleistocene outcrop (Dahm, 1983). Shepherd *et al*., (2000), classified the island into two distinct part; the larger seaward part comprises a 24 km distance of Holocene sand barrier that stretches parallel to the oceanic shoreline and the harbourside part, which adjoins the centre of the Holocene barriers, consists of Pleistocene terraces overlain by a mantle of tephra and other cover deposits (fig. 2).

From the geomorphic features described in Shepherd *et al*., (1997 & 2000), it appears that there were 4 tidal inlets prior to 5000 BP; the present day Katikati and Tauranga inlets, the Blue Gum Bay entrance, and an entrance between Matakana and Rangiwaea islands (fig. 2). Spit extension of both ends of Matakana Island and the formation of the successive foredunes as the shoreline prograded seawards are suggestions for the closure of the middle two entrances. Migration of tidal inlets and the eventual entrance closures naturally influenced the position and stability of the attached ebb-tidal deltas.

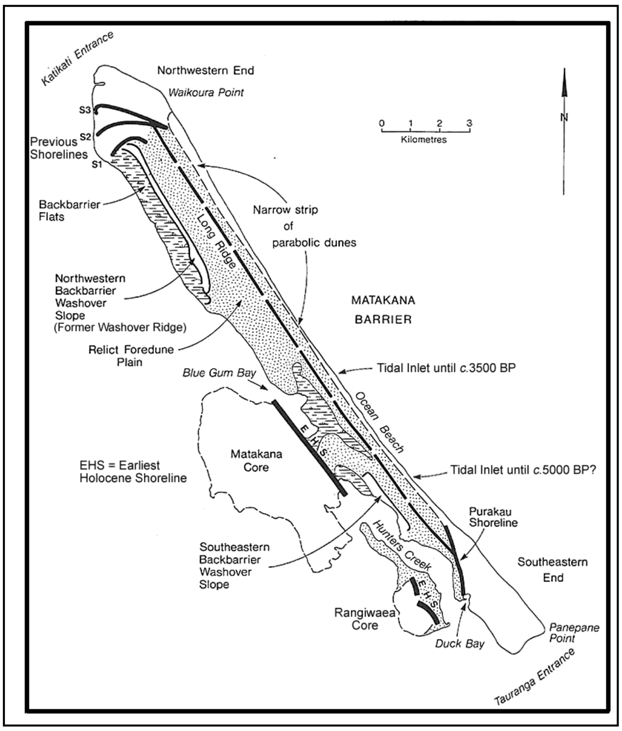

Figure 2 Shows the major geomorphological units of Matakana Island and the locations of former tidal inlets. After figure 7 of Shepherd *et al*., (1997).

The southeastern end of Matakana Island, Panepane Point (fig. 1), was eroded back to the Purakau Shoreline by a tsunami in the early 15th Century. Since then it has prograded southeast by about 3 km (500 m since the first survey in 1852), resulted in narrowing of the Tauranga Harbour Entrance. Tidal inlet narrowing may lead to increased velocities of the flood and ebb jet flows through the inlet, which is an important influence on the sedimentation of the ebb tidal delta (Spiers *et al*. , 2009). The evolution of Matakana Island, particularly Panepane Point, suggests that the impact of the periodic maintenance dredging program on the stability of the ebb-tidal delta may be less than natural processes.

DREDGED VOLUMES

The first dredging campaign was conducted in 1968 by the Port of Tauranga Ltd. to create the 7 km Entrance Channel. A second capital campaign in 1992, deepened and widened the channel (fig 1). Biannual maintenance dredging programmes maintain the channel at its' design depth. During 1998 – 2010, the maintenance dredged material totalled 1.5 million cubic in volume for the whole harbour. Over this period, the largest single dredged volume of about 259,193 m^3 was taken in 2008 from the Entrance Channel from a total of 406,961 m^3 around the Tauranga Harbour (Table 1).

Table 1 Volumes of dredged materials around Tauranga Harbour during 1998 – 2010.

Year	Entrance Channel	Total
1998	-	136,000
2002	176,662	327,271
2004	171,674	350,432
2006	122,724	276,398
2008	259,193	406,961
2010	9,209	45,527

METHODS AND RESULTS

Ebb-Tidal Delta Bathymetry and Sand Volume Variability

Based on the analysis of annual surveys and volumetric calculations, Brannigan (2009) found that the Matakana ebb-tidal delta generally remained stable between 1989 and 1995, but considerable localised changes were apparent. He also found that there was no significant changes on the shoreline of southeastern Matakana Island near the ebb-tidal delta as the result of 1991-1992 dredging.

In this study, continuous bathymetric data covering the vicinity of Tauranga Harbour provided by the Port of Tauranga Ltd. were analyzed in order to describe the stability of the ebb-tidal delta and its volumetric changes. Bathymetric data were supplied for surveys undertaken in 1998, March 1999, March 2000, June 2001, August 2002, July 2005, 2006, August 2008, November 2009, November 2010 and November 2011. Hydrographic surveys employed a single-beam Knudsen 320M echosounder operating on frequency of 210 kHz with a 9 degree beam width and range scale 20 m. Raw data from the surveys were formatted as x, y and z values representing the longitude and latitude coordinates (UTM coordinate system), and depth respectively. The approach used in analyzing the ebb tidal delta shapes and volumes utilized the SURFER 10 package (Golden Software, 2011). The location and elevation xyz data were gridded into 20 m spacing by the krigging method, resulting in bathymetric maps that spanned about 3.5 km in both the cross- and along-shore directions. All bathymetry maps generated used the same grid in order to be comparable one to another.

Volume differences between 2 successive surveys were gained by subtracting the same grid points of two different years (Hicks and Hume, 1996; 1997). In SURFER 10, the volume is calculated by three different algorithms; Trapezoidal Rule, Simpson's Rule and Simpson's 3/8 Rule, including the Cut and Fill calculations. After using all three methods, the mean value was taken as the total volume (Table 2).

Residual contours were also obtained from substracting the depth (z) value of two different years (fig. 3) and the surface areas where accretion and erosion occurs can be determined from the residual contour map (Table 2) by using the areas of polygons which were overlaid on the regions of erosion or accretion.

As the result of volumetric calculation and residual contour analysis, it is clearly seen that the most volumetric changes occurred related to depths changes over the shallow swash bar. The volume changes appear larger. For example, between 2006 to 2008, the ebb-tidal delta accreted about 18 Mm^3 over about 76% of the total ebb-tidal delta area. The greatest volume of erosion occurred between 2009 to 2010, when about 14 Mm^3 sediment were loss from about 68% of the total ebb-tidal delta area. For the entire period of 13 years of observation, the ebb tidal delta had accreted by about 7 Mm^3 (Table 2). These changes are comparable to the 15 Mm^3 capital dredging program planned for port expansion.

It was considered possible that the observed changes resulted from the movement of swash bars, and their positions relative to the survey transects at the time of the survey. If this were the case, the observed volumetric changes would represent a redistribution of the sediment within the delta, and not necessarily losses and gains for the total delta volume.

Cross-section profiles were generated to help visualize the bathymetric changes and to track the migration of the swashbars. Each bathymetric map was subdivided by 7 cross-shore profiles, from the most southeastern to northwest of the ebb-tidal delta, and the results are illustrated in fig. 4. Figure 5 consists of shaded surface plots of the bathmetric maps, with superimposed depth contours 1 m, 5 m, 10 m and 15 m during the observation period. This highlights the variability attributed to the migration of swash bars.

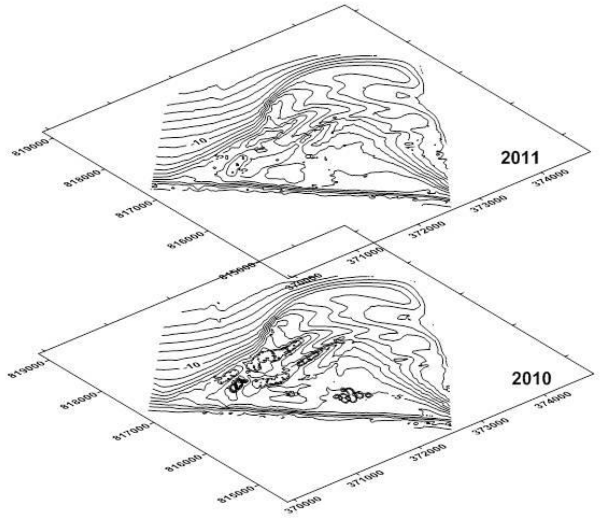

Fig. 3 Method used for the volume changes between 2 successive surveys, the bathymetry of subsequent year subtracted to the previous one (i.e. z2011 – z2010).

Table 2 Volumetric changes and the surface areas where erosion and accretion occurred on the Matakana Banks ebb-tidal delta over period 1998 to 2011. Volumes with negative values denote erosion.

Surveys	**Volumetric changes (m^3)**	**Affected Areas**		
		Erosion (m^2)	**Accretion (m^2)**	**Total Area (m^2)**
March 1999 - April 1998	- 5,853,244	7,298,882	3,842,513	11,141,395
March 2000 – March 1999	3,292,265	4,127,925	7,138,856	11,266,782
June 2001 – March 2000	3,683,616	4,195,099	7,160,759	11,355,858
Aug 2002 – June 2001	- 4,335,961	8,502,050	3,170,386	11,672,436
2006 – Aug 2002	- 7,603,186	6,676,014	3,403,491	10,079,505
Aug 2008 - 2006	18,953,459	1,896,319	6,084,352	7,980,671
Nov 2009 – Aug 2008	11,463,426	2,263,364	8,122,995	10,386,359
Nov 2010 – Nov 2009	- 14,164,660	7,144,001	3,350,828	10,494,829
Nov 2011 – Nov 2010	-11,246,173	9,547,381	1,318,820	10,866,201
Nov 2011 – April 1998	7,078,462	3,645,769	6,746,417	10,392,187

Characteristics of an ebb-tidal delta are described by FitzGerald *et al*., (2012), and emphasis that sediment is dispersed laterally in a net seaward direction from the tidal inlet by the ebb tidal jet, and is eventually deposited on the terminal lobe as the velocity decreases. The sediment transport associated with the ebb jet is evident as northwards migrating sand waves appearing on the right hand (eastern) side of the surface plots in fig. 5. These sand waves contribute to the variability observed in the 10 m contour. Overall, the bathymetric changes are consistent with offshore sediment transport of sediment via migrating bedforms in the pre-dredging ebb channel. The sand waves contribute sediment to the terminal lobe when the ebb current velocity weakens.

There is also evidence of the migration of swash bars in response to wave action. To simplyfy the analysis of cross-shore profiles, the 7 profiles (fig. 4) are divided into 3 groups: group A includes profile 1, 2 and 3; B for 4 and 5; and group C of profile 6 and 7.

The height variation and lateral migration of the swash bars are significantly different among the groups. Group A, which adjoins the tidal inlet, shows less variability in bar migration than showed by group B.

At profile 1 (group A), the swash bars migrated seaward, but further than 2,000 m offshore, the swash bars are more stable, with bed elevation variations less than 2 m. Profile 2 shows gently sloping surface with the first sand bar developed 2,200 m from the shoreline.

During the period of observation, this first sandbar migrated 200 m offshore producing erosion of up to 4 m from the initial bed elevation. The outermost swash bar at 3,350 m offshore shows almost no variability (more stable).

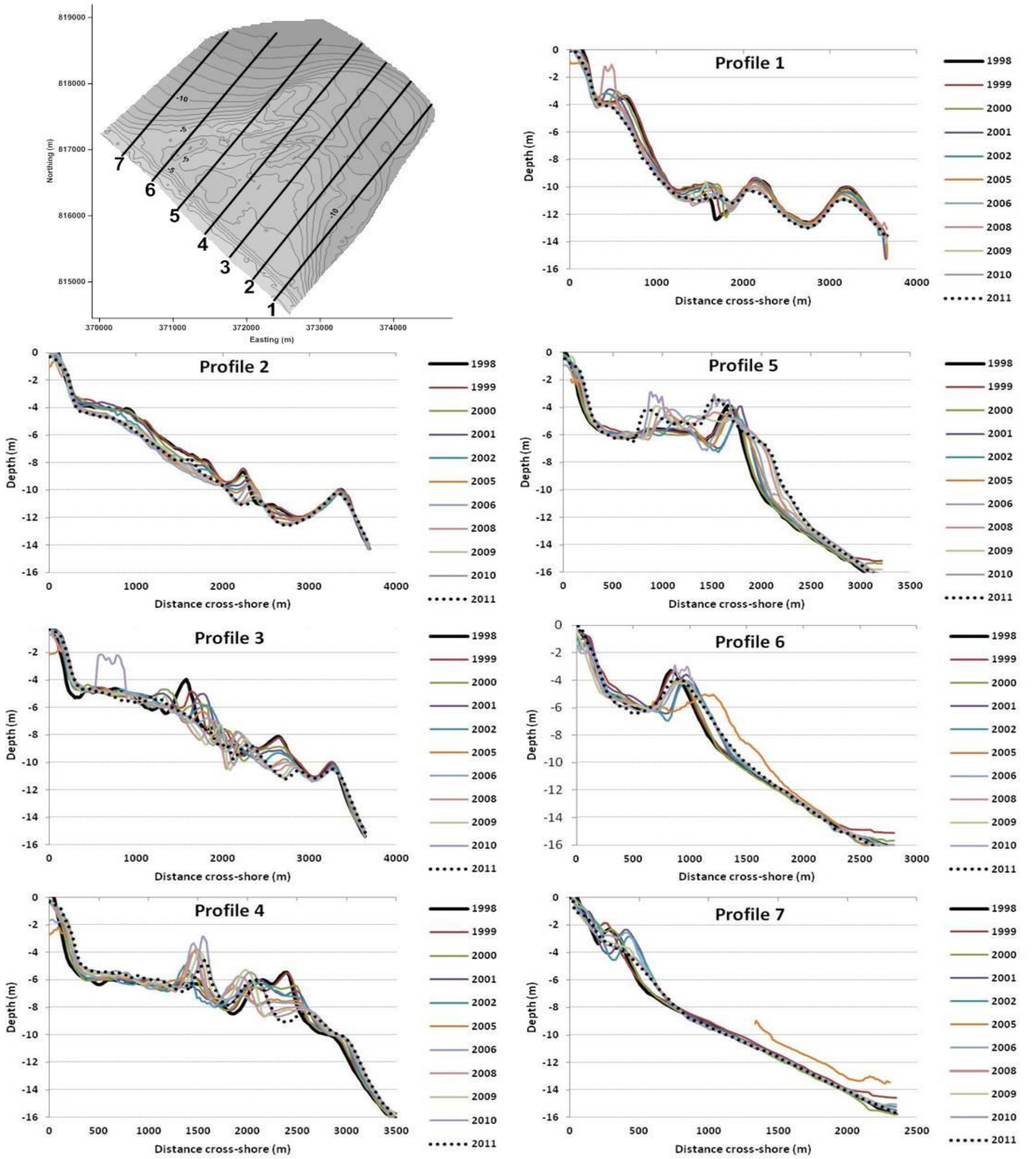

Figure 4 Cross-section profiles 1 to 7 aligning from the southeast to northwest Matakana Banks ebb-tidal delta show that themost dynamic area on an ebb-tidal delta is at its swash platform where the waves break. The least dynamic is at the most northwest (terminal lobe) as the ebb current is weakened.

In profile 3, erosion dominates, and offshore swash bar migration becomes more intense beyond 1,400 m from the shoreline. Beyond 3,000 m, the there appear to be stable marginal bars. Over the entire observation period, up to 4 m of erosion was associated with the bar migration.

It is inferred that the changes in group A profiles are dominated by ebb tidal currents, resulting in offshore migration of sediment, which may eventually result in the terminal lobe shifting offshore.

Group B, which dissected the main swash platform of the ebb-tidal delta, shows the most intensive swash bar migration at depths between 3 and 11 m. Profiles 4 and 5 were dominated by accretion, and the swash bars migrated shoreward. At profile 4, it is seen that the sand

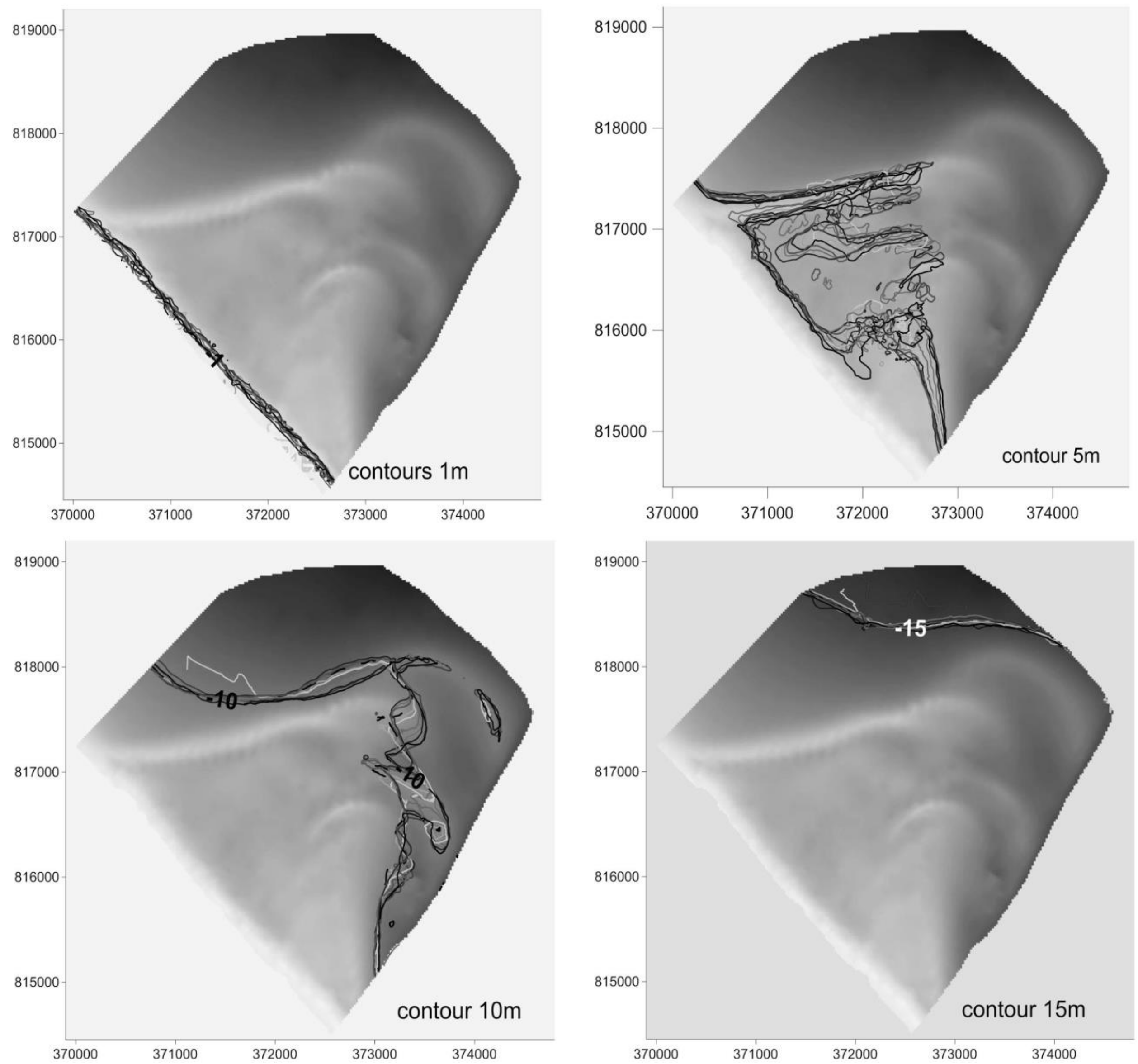

Figure 5 The positions of depths -1 m, -5 m, -10 m and -15 m reflect the bathymetry variability and the swash bars migrations on the ebb tidal delta.

bars shifted shoreward, starting at a distance of 2,500 m from the shoreline. Beyond this point, starting from a water depth of 8 m, there was up to 2 m of accretion from 1998 to 2011. Accretion of up to 4 m during the observation period also occurred between 1,900 m to 2,200 m along profile 5.

Group C covers the region where the swash platform narrows and welds onto the offshore bars of Matakana Island. During the observation period, the outer bar on profile 6 shifted about 200 m offshore. Meanwhile, profile 7 became flatter and about 1.5 m lower than the original level in 1998.

Figure 5 describes the changes of specific depth contours, superimposed on the shaded surface map for the 2011 survey.

The 1 m depth contour is taken to represent the shoreline, as the bathymetric data did not include 0 m shoreline elevations.

The shoreline seems to have been stable during the observation period. However, further offshore, on the swash platform and at the shoreward side of terminal lobe as were described in the cross-section profiles, the morphology at depths 5 m to 10 m are more variable with the movements of the sand waves and swash bars toward on- and offshore. Beyond the terminal lobe, which is represented by the 15 m contour, the seabed seems to be more stable suggesting the 15 m contour is a good indicator of the outermost limit of the ebb-tidal delta.

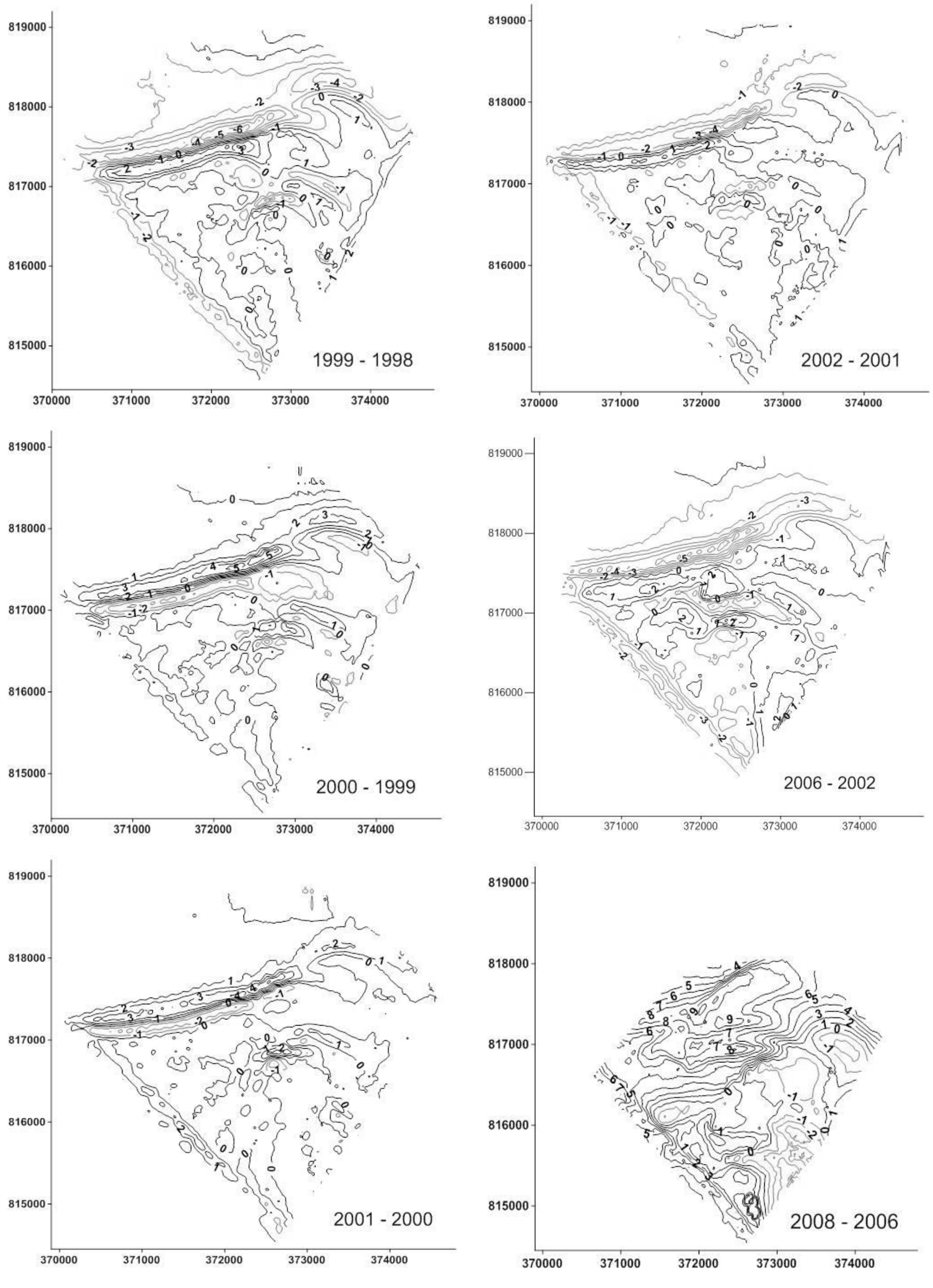

Fig. 6 Residual contours show the bathymetric differences between two surveys and the areas where accretion (black contour) and erosion (brown contour) occur.

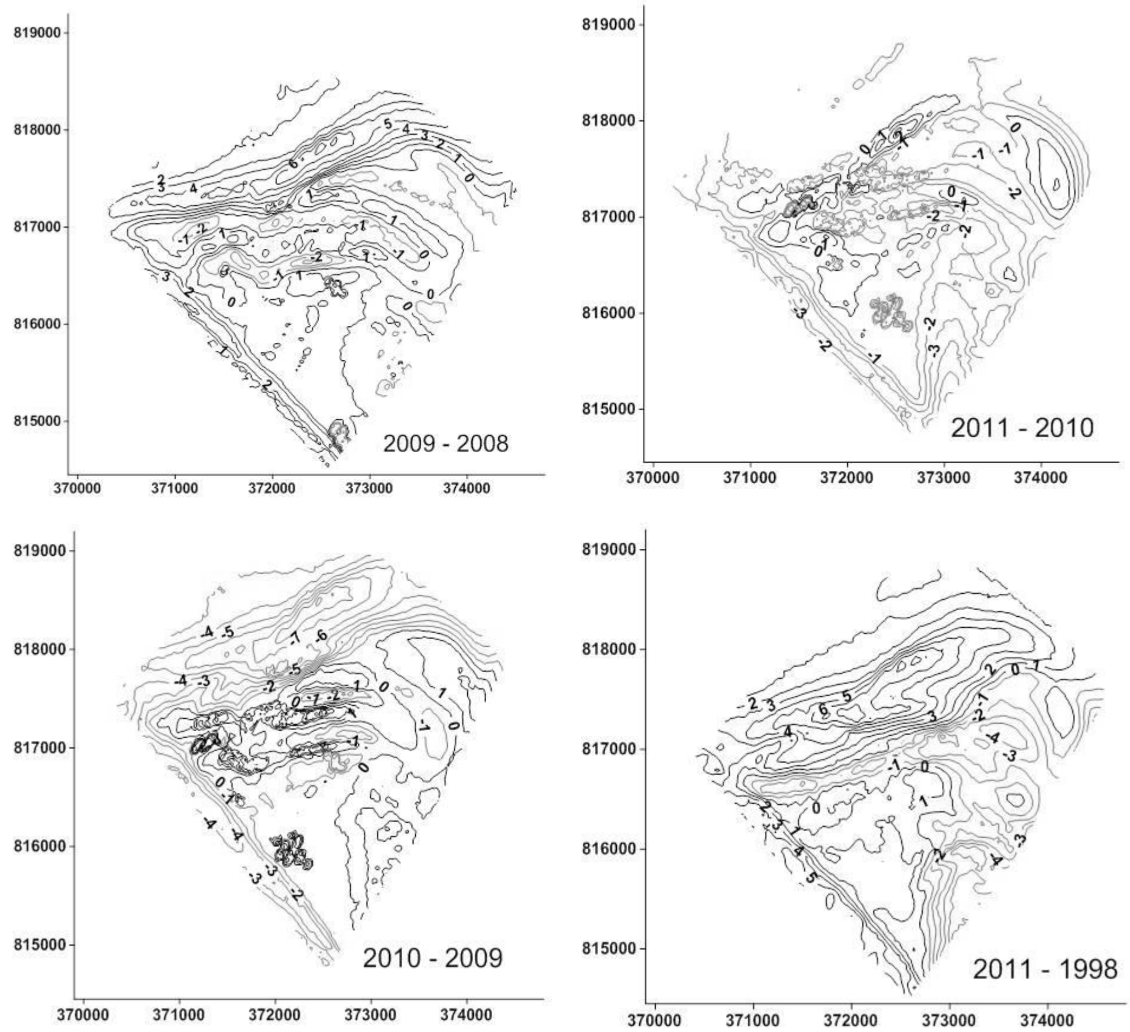

Fig. 6 (*continued*) Residual contours show the bathymetric differences between two surveys and the areas where accretion (black contour) and erosion (brown contour) occur.

Sediment Availability, Current and Wave Measurements

The mobility of sediment on the ebb-tidal delta that generates morphological changes is related to the capability of the wave and tidal currents to move and transport sediments, and the quantity of suitable sediment available. The rates and magnitude of the longshore sediment transport along Matakana Island and in the vicinity of Matakana Banks ebb-tidal delta is still uncertain (Healy and de Lange, in press). Based on the spatial distribution of magnetite minerals along the innershelf between Waihi Beach and Omanu Beach east of the Tauranga Harbour, the longshore transport along Matakana Island and the vicinity of Matakana banks ebb-tidal delta is bidirectional, but the predominant movement is southeasterly (Badesab *et al*., 2012).

In order to quantify the direction and magnitude of longshore transport along Matakana Island, hydrodynamic forces should be identified and quantified as they drive sediment transport and are required to calibrate and verify numerical models (van Rijn, 2007). Thus, in an attempt to identify and quantify the hydrodinamic forces roled in the study area, a field programme was planned for April-May 2013 to cover the hydrodynamic regime during storm and non-storm, summer and winter periods, and include at least one whole neap-spring tidal cycle.

This was intended to assess the stability of ebb tidal delta under various hydrodynamic regimes and it is also planned that the future measurements will be conducted before and after dredging to assess any impact to the study site.

The first measurement has been conducted on 11th April 2013 to cover the autumn season, and tidal ranges of 1.1 m to 2 m (MetService, 2013). Autumn is often windy, and three storm events occurred during the field programme.

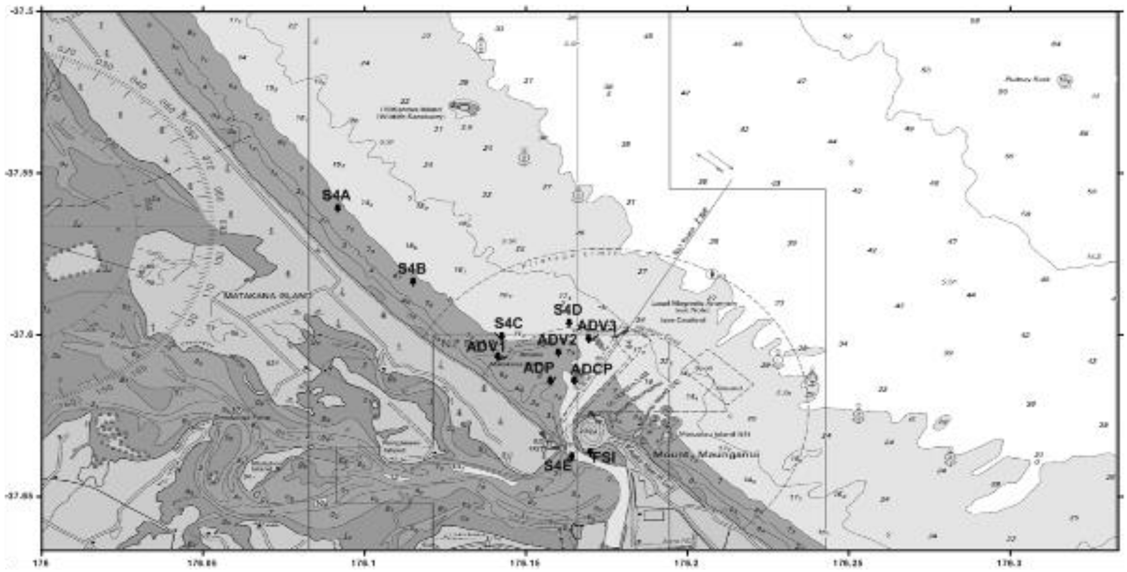

Figure 7 Location of instruments to measure wave, currents and sediment availability.

Figure 8 Instruments for measuring the wave and current magnitudes and directions. The first picture shows the S4 (A) current meter that is equipped with a C3 submersible fluorometer (B), a sediment trap (C) and a pinger (D). The second picture shows the ADV (E) with sediment traps and the third picture shows the ADCP (F) for current direction and velocity along the water coloum.

Eleven observation sites were located within the harbour entrance and on the Matakana ebb-tidal delta (fig. 7, Table 3). The instruments were all installed in frames and anchored on the seabed by SCUBA divers. Each of frames was equipped with a sediment trap to collect the sediments being transported as they settled down when the current waned (fig.8C). Sediment traps were serviced every 1-2 weeks depending on the sedimentation rates and weather conditions.

Instruments were set to collect short and long period waves, current magnitudes and directions, and turbidity in the water column over a 30-40 day duration (Table 3). A pinger was attached to each frame to assist with finding the instruments for servicing and recovery at the end of deployment period.

Table 3 Instrument settings

INSTRUMENTS	SETTINGS
Interocean S4 current meter	sampling interval 300 sec, avaraging interval 60 sec.
Turner C3 fluorometer	sampling interval 30 minutes, only use 1 sensor (channel setting) for turbidity.
Acoustic Doppler Velocimeter	sampling interval 300 sec, avaraging interval 60 sec.
Acoustic Doppler Current Profiler	avaraging interval 120 sec, burst interval 2 sec, sampling frequency 1200 Hz, depth cell size 0.5 m.
Argonaut Acoustic Doppler Profiler	frequency 3 MHz, avaraging interval 60 sec, sampling interval 300 sec, blanking distance from bottom 0.2 m, bin size 0.6 m, number of cells 10.
FSI current meters	burst interval 60 sec, avaraging interval 20 minutes, calculate 3DWave.
Scufa fluorometer	sampling interval 5 minutes
RBR submersible tide gauge	sampling interval 1 minute

DISCUSSION AND CONCLUSIONS

The stability of an ebb-tidal delta is primarily dependent on the morphodynamic behaviour of the ebb-tidal delta, particularly the interactions of tidal currents, wave action and available sediment. To assess the ebb-tidal delta variability over time, bathymetry data from repeated hydrographic surveys using a single beam echo sounder conducted by the Port of Tauranga from 1998 to 2011 were analyzed. The results show that the ebb tidal delta morphology over this period changed in response to the migration of sand waves in the main ebb channel, and swash bars over the swash platform. This was reflected in moving zones of apparent erosion and accretion.

Three main zones were recognized: close to the main ebb channel; the main swash platform; and the region where the ebb tidal delta welds onto the barrier island shoreline. Close to the ebb tidal channel, the net movement of sediment was offshore; firstly as sand waves on the floor of the channel, and secondly as swash bars on the terminal lobe. This behaviour appears to have been dominated by the ebb jet. On the main swash platform, the swash bars migrated landwards, primarily in response to wave action. Finally close to the shoreline, the changes were relatively small, and involved a slight seaward migration of the terminal lobe. The swash bars in this region did not appear to change position.

During the survey period, there were several episodes of maintenance dredging. However, no obvious morphological changes could be linked to the dredging. The most likely effect that the maintenance dredging could have is to divert some of the ebb jet eastwards into the Entrance Channel, which may reduce the seaward transport associated with the ebb jet. This was not evident in the bathymetric data analysed. It has previously been reported that there are wave climate variations with ENSO fluctuations (de Lange, 1993). These variations most likely affect the landward migration of swash bars on the swash platform, particularly the storm driven transport.

The field programme was undertaken to obtain quantitative data for the hydrodynamic forcing over the delta, combined with multibeam echosounder surveys. These data will allow a better conceptual model to be developed to characterize the main processes operating for the 3 zones identified, and the associated morphological responses. The field programme was undertaken during ENSO-neutral conditions (neither El Niño nor La Niña) (NIWA, 2013). Once the relationship between forcing and ebb tidal delta response is determined, it will be possible to better forecast the potential effects of future capital dredging.

.

REFERENCES

Badesab, F., von Dobeneck, T., Bryan, K.R., Mueller, H., Briggs, R.M., Frederichs, T., and Kwoll, E. (2012). Formation of magnetic-enriched zones in and offshore of a mesotidal estuarine lagoon: An enviromental magnetic study of Tauranga Harbour and Bay of Plenty, New Zealand. *Geochemistry, Geophysics, Geosystem Vol. 13, No. 6*, 1-20.

Brannigan, A. (2009). *Change in Geomorphology, Hydrodynamics and Surficial Sediment of Tauranga Entrance Tidal Delta System (MSc Thesis)*. Hamilton, New Zealand: University of Waikato.

Bruun, P., and Gerritsen, F. (1960) *Stability of coastal inlets*. Amsterdam, North-Holland Publishing Co. 123 p.

Dahm, J. (1983). *The Geomorphic Development Bathymetric Stability and Sediment Dynamics of Tauranga Harbour. MSc Thesis in Earth Science.* Hamilton, New Zealand: Univerrsity of Waikato.

de Lange, W. (1993). *Wave Climate for No. 1 Reach, Port of Tauranga, Tauranga Harbour, Report to the Port of Tauranga Ltd.* Hamilton, New Zealand.: Department of Earth Sciences, University of Waikato.

FitzGerald, D.M. (2005). Tidal inlets. *In* Schwartz, M.L. (ed.), *Encyclopedia of Coastal Science*. Dordrecht, Springer, pp. 958-965.

FitzGerald, D., Buynevich, I., and Hein, C. (2012). Morphodynamics and Facies Architecture of Tidal Inlets and Tidal Deltas. In J. R. Davis, *Principles of*

Tidal Sedimentology (pp. 301-333). Springer Science+Business Media.

Foster, G. H. (1994). Sediment Budget and Equilibrium Beach Profiles Applied to Renourisment of an Ebb Tidal Delta Adjacent Beach, Mt. Maunganui, New Zealand. *Journal of Coastal Research*, 564-575.

Gibb, J. (1986). A New Zealand Regional Holocene Eustatic Sea Level Curve and Its Application to Determination of Vertical Tectonic Movements. A Contribution to ICGP-Project200. *International Symposium on Recent Crustal Movements from the Pacific Region. Journal of The Royal Society of New Zealand, Bulletin 24.*, 377-395.

Healy, T.R., Mathew, J., de Lange, W.P., and Black, K. (1996). Adjustment toward Equilibrium of a Large Flood-Tidal Delta after a Major Dredging Program, Tauranga Harbour, New Zealand. *Coastal Engineering*, 3284-3294.

Hicks, D.M. and Hume, T.M. (1996). Morphology and Size of Ebb Tidal Deltas at Natural Inlets on Open-sea and Pockect-bay Coasts, North Island, New Zealand. *Journal of Coastal Research*, 47-63.

Hicks, D.M. and Hume, T.M. (1997). Determining sand Volumes and Bathymetric Change on an Ebb-Tidal Delta. *Journal of Coastal Research*, 407-416.

Krueger, J.C., and Healy, T.R. (2006). Mapping the Morphology of a Dredged Ebb Tiidal Delta, Tauranga Harbour, New Zealand. *Journal of Coastal Research*, 720-727.

NIWA. (2013, April 30). *National Institute of Water and Atmospheric Research*. Retrieved from Seasonal Climate Outlook: January-March 2013: http://www.niwa.co.nz/climate/sco/seasonal-climate-outlook-january-march-2013

Shepherd, M.J., Betts, H.D., McFadgen, B.G., and Sutton, D.G. (2000). Geomorphological Evidence for Pleistocene Barrier at Matakana Island, Bay of Plenty, New Zealand. *New Jealand Journal of Geology and Geophysics, Vol. 43*, 579-586.

Shepherd, M.J., McFadgen, B.G., Betts, H.D., and Sutton, D.G. (1997). Formation, Landforms and Palaeoenvironment of Matakana Island and Implications for Archaeology. *Science and Research Series No. 102: Wellington, Department of Conservation.*, 1-102.

Spiers, K.C. (2005). *Continued beach renourishment from dredge spoil disposal (MSc Thesis)*. Hamilton, New Zealand: University of Waikato.

Spiers, K.C., Healy, T.R., and Winter, C. (2009). Ebb-Jet Dynamics and Transient Eddy Formation at Tauranga Harbour: Implications for Entrance Channel Shoaling. *Journal of Coastal Research*, 25: 234-247.

van Rijn, L. (2007). *Manual of sediment transport measurements in rivers, estuaries, and coastal seas.* The Netherlands: Aqua Publications.